Introduction: Cervical spinal cord injury without radiographic abnormality often occurs in falling or traffic accidents. The consequent cervical hyperextension is thought to be the mechanism of injury since most victims have lacerations or contusions on their faces. Some recent studies using magnetic resonance imaging have revealed that cervical spinal cord injuries without bony damage occur predominantly at C3-4 levels where there are usually fewer spondylotic changes and a wider spinal canal diameter, compared to lower segments. We propose that the cervical spine would show a particular motion beside extension in which the impact force would concentrate on C3-4 motion segment during direct face impact.

Methods: The subjects were five healthy male volunteers. They were seated on a specially designed chair and low-level backward impact loads were applied to their maxilla via a strap using a free falling 3 kg mass (Figure 1). Two accelerometers were attached to the subject’s head using bite blocks and muscle activity was monitored in all tests using electromyography. Cervical vertebral motions were recorded by means of X-ray cineradiography at a speed of 60 frames per second (Cine-system: Philips BH5000, Cine-Camera: nac Arritechno 35) during direct face impact. Templates of cervical spine for each subject were made on a personal computer and superimposed on the cervical vertebrae of each image (template method [1]). The angles relative to the horizontal plane were calculated from the positions of the anterior-inferior points and the posterior-inferior points of each vertebral template using software (Mathematica, Wolfram Research, Inc.). The shear and axial forces to the neck were calculated from the data measured by accelerometers and estimated head weight [2]. The Ethics Committee of Tsukuba University had previously approved the experimental protocol.

Essential results: In a representative experiment, posterior shear force was applied to the neck at about 20 to 180 ms and reached a maximum force at about 70 ms. Figure 2 shows representative rotational angles of each vertebra with respect to C7. After direct face impact, the occipital condyle and C1 were flexed immediately and after they reached their maximum flexion at about 110 ms, their motion changed to extension. C2 flexion began at approximately 40 ms and after C2 reached its maximum flexion at about 130 ms, it changed its motion to extension. In contrast, C4, C5, C6 showed extension motion without flexion after the impact. That is, the occipital condyle, C1, C2, and C3 were flexed during the initial phase of the impact (initial flexion) and their motion changed to extension, while lower segments were extended during the impact load to the face. Thus, the cervical spine showed a two-phase curvature, which had an inflection point at C3-4 around 130 ms.

Discussion: In this experiment, most of the applied impact load to the face resulted in a posterior shear force to the head and occipital condyle; C1, C2, and C3 were thrust backward in a flexion motion (flexion-translation) during the early phase of the impact. Therefore, the cervical spine showed a two-phase dynamic curvature, having an inflection point at the C3-4 level. We propose that an actual impact to the face forces the cervical spine into similar motion and greater shear force results in the temporary posterior translation of C3 relative to C4 causing spinal cord compression (Figure 3).